

1. PI and Co-I Names and Affiliations

Stephen E. Schwartz; Rangasayi N. Halthore

2. Title of Research Grant

Shortwave Radiative Forcing by Tropospheric Aerosols

3. Scientific Goal(s) of Research Grant

This project consists of experiments with data from the Department of Energy Atmospheric Radiation Measurement Program Southern Great Plains site to determine aerosol shortwave radiative forcing and its relation to aerosol column optical depth and mass loading and size distribution at the surface and vertically when available. Parameterizations of aerosol light-scattering properties necessary to describe this forcing based on mass loading of the aerosol will be developed and evaluated. These parameterizations will explicitly account for size dependence of scattering cross section and upscatter fraction, including relative humidity influences. Uncertainty in these quantities is a major contributor to the uncertainty in shortwave forcing due to anthropogenic aerosols, which is presently estimated at about -1 watts per square meter, global average, uncertain by at least a factor of 2. In industrialized regions the average aerosol forcing is an order of magnitude greater, and the instantaneous forcing can be several-fold greater still, -30 to -50 watts per square meter, a substantial perturbation on the shortwave budget that must be accounted for in measurements and models. The product of this project will be parameterizations, of reduced and known uncertainty, for representing aerosol forcing in climate models based on mass loading of pertinent aerosol substances.

4. Accomplishments

Closure experiments on diffuse downwelling solar irradiance. A closure experiment involving measurement and calculation of diffuse downward irradiance (DFDI) under cloud-free conditions at the surface performed at various locations with many independently calibrated instruments and several independently developed radiative transfer models, reveals that the model calculations consistently over-predict the measurements by 25 to 45% regardless of the amount of turbidity in the atmosphere or the type of model used to solve the transfer equation. Reduction in apparent vertical aerosol optical thickness (AOT) at all wavelengths of 0.02 to and a corresponding increase in atmospheric absorption to conserve sun photometer measured atmospheric transmittance, decreases the calculated DFDI to the measured value. The required increase in atmospheric absorption required to close the gap between calculations and measurements of DFDI is a major portion of the reported anomaly in atmospheric absorption observed under cloudy and clear skies.

Closure experiments between measured and calculated aerosol optical depth. Comparison of aerosol optical depth (AOD) determined by sun photometry at the Southern Great Plains (SGP) Atmospheric Radiation Measurement (ARM) site in north central Oklahoma for several cloud-free days with estimates of AOD based on aerosol extinction measured at the surface (taken as the sum of the aerosol scattering and absorption coefficients). Micropulse lidar profiles of normalized aerosol backscatter are used to estimate the vertical profile of aerosol extinction. The resulting AOD's agree with measured AOD's within an uncertainty of ~20% when hygroscopic growth is accounted for. We have participated in

evaluation of aerosol extinction derived from Raman Lidar by comparison with sunphotometric measurements. Aerosol optical thicknesses (AOT) were computed by integrating the Raman lidar aerosol extinction profiles between the surface and 7 km. The average bias difference between the Raman Lidar and Sun photometer AOT values was less than 5%.

Determination of aerosol direct radiative forcing. Direct shortwave radiative forcing of climate by an aerosol is the difference between radiative flux in the presence of the aerosol and in its absence. The aerosol perturbation in radiative flux depends on the aerosol properties column extinction, the fraction of extinction that is scattered (single scattering albedo), and the angular distribution of light scattering, as well as the geophysical variables solar zenith angle, surface reflectance, and atmospheric transmittance above the aerosol. Aerosol optical properties and atmospheric radiation components at the surface have been used to determine surface and top-of-atmosphere aerosol radiative forcing at the ARM SGP site.

5. Progress and accomplishments during last twelve months (or from beginning of the current effort whichever is shorter).

See 4 above.

6. As appropriate attach one or so electronic figures with paragraph discussions highlighting current research. Label with PI name, affiliation, and year. We will use these in presentation materials.

Figures are at the end of this report.

7. List all *refereed* publications either submitted or published during the *current* grant FY that acknowledge DOE ARM support.

2000

Bergin, M. H., S. E. Schwartz, R. N. Halthore, J. A. Ogren, and D. L. Hlavka. Comparison of Aerosol Optical Depth Inferred From Surface Measurements with that Determined by Sun Photometry for Cloud-Free Conditions at a Continental U.S. Site. *J. Geophys. Res.* 105, 6807-6816 (2000).

Halthore, R. N., and S. E. Schwartz. Comparison of Model Estimated and Measured Diffuse Downward Surface Irradiance in Cloud-Free Skies. *J. Geophys. Res.*, in press, 2000.

Kato S., M. H. Bergin, T. P. Ackerman, T. P. Charlock, E. E. Clothiaux, R. A. Ferrare, R. N. Halthore, N. Laulainen, G. G. Mace, J. Michalsky, and D. D. Turner, "A comparison of the aerosol optical thickness derived from ground-based and airborne measurements." *J. Geophys. Res.*, in press, 2000.

Peppler R. A., C. P. Bahrmann, J. C. Barnard, J. R. Campbell, M.-D. Cheng, R. A. Ferrare, R. N. Halthore, L. A. Heilman, D. L. Hlavka, N. S. Laulainen, C.-J. Lin, J. A. Ogren, M. R. Poellot, L. A. Remer, K. Sassen, J. D. Spinhirne, M. E. Splitt, and D. D. Turner. "ARM Southern Great Plains Site Observations of the Smoke Pall Associated with the 1998 Central American Fires." *BAMS*, submitted, 2000.

Schmid B., J. J. Michalsky, D. W. Slater, J. C. Barnard, R. N. Halthore, J. C. Liljegren, B. N. Holben, T. F. Eck, J. M. Livingston, P. B. Russell, T. Ingold, and I. Slutsker, Comparison of columnar water vapor measurements during the fall 1997 ARM Intensive Observation Period: solar transmittance methods. *Appl. Optics*, submitted, 2000.

Schwartz S. E., and P. R. Buseck. Absorbing Phenomena. *Science* 288, 989-990 (2000).

1999

Walthall C. L., R. N. Halthore, S. E. Loechel, G. C. Elman, and B. L. Markham. Measuring Aerosol Optical Thickness with a Helicopter-Based Sunphotometer. *IEEE Trans. Geosci. Remote Sensing*, accepted, 1999.

Halthore, R. N. Measurement and Modeling of Shortwave Irradiance Components in Cloud-Free Atmospheres. *Recent Res. Devel. Geophys.* 2, 125-129 (1999).

Schmid B., J. J. Michalsky, R. N. Halthore, M. C. Beauharnois, L. C. Harrison, J. M. Livingston, P. B. Russell, B. N. Holben, T. F. Eck, and A. Smirnov. Comparison of aerosol optical depth from five solar radiometers during the fall 1997 ARM intensive observation period. *Geophys Res. Lett.* 26, 2725-2728 (1999).

8. List all published (either paper or web-based) extended abstracts in the current FY that acknowledge DOE ARM support.

2000

Ferrare, R. A., D. D. Turner, L. A. Heilman, W. F. Feltz, R. Peppler, and R. Halthore. Raman lidar profiling of water vapor and aerosols over the ARM SGP Site, Abstract for presentation at the Symposium on Lidar Atmospheric Monitoring, American Meteorological Society, Long Beach, CA, 9 – 14 January, 2000. Paper 2.1; Extended Abstract, 4 pp.

Schwartz, S. E., Aerosols and ARM, 10th Annual ARM Meeting, San Antonio, Texas, March 13-16, 2000. <http://www.ecd.bnl.gov/steve/ARMaerosol.pdf>

Schwartz, S. E., and R. N. Halthore. Measurement of Aerosol Shortwave Direct Forcing at the ARM SGP Site, 10th Annual ARM Meeting, San Antonio, Texas, March 13-16, 2000. Poster. http://www.ecd.bnl.gov/steve/SW_forc_SGP.pdf

1999

Halthore, R. N. Intercomparison of shortwave radiative transfer codes and measurements. Ninth Annual ARM Meeting, San Antonio, Texas, March 22-26, 1999. [BNL-66165-AB]

Halthore, R. N., A. Cialella, B. L. Markham, J. Seiferth, and W. Gao. Calibration of LANDSAT-5 tm sensor using ARM data. 9th Annual ARM Meeting, San Antonio, Texas, March 22-26, 1999. [BNL-66167-AB]

Halothore, R. N., S. E. Schwartz, and E. G. Dutton. Diffuse shortwave irradiance at surface - further issues and implications. 9th Annual ARM Meeting, San Antonio, Texas, March 22-26, 1999. [BNL-66164-AB]

Halothore, R. N., S. E. Schwartz, Y. Liu, P. Daum, B. Holben, and J. J. Michalsky. Sun and sky radiometric measurements at the CART ARM SGP site. 9th Annual ARM Meeting, San Antonio, Texas, March 22-26, 1999. [BNL-66166-AB]

Halothore, R. N. Some results of the intercomparison of shortwave radiative transfer codes and measurements. American Geophysical Union Fall Meeting, December 13-17, 1999, San Francisco. Paper A51F-09. Abstract: Eos Trans. Amer. Geophys. Un. 80(46), Fall Meet. Suppl., F235 (1999).

Michalsky, J., B. Schmid, R. Halothore, C. Pavloski, T. Ackerman, M. Beauharnois, L. Harrison, J. Livingston, and P. Russell. Comparison of sunphotometric measurements during the Fall 1997 ARM intensive observation period. 10th Conference on Atmospheric Radiation: A Symposium with Tributes to the Works of Verner E. Suomi, Madison, WI, 28 June-2 July, 1999. [BNL-66169-AB]

Peppler, R. A., L. Ashford, C. P. Bahrmann, R. A. Ferrare, R. N. Halothore, F. J. Murcray, J. A. Ogren, M. R. Poellot, P. Sheridan, M. E. Splitt, and D. D. Turner. Identification and analysis of the 1998 central American smoke event at the SGP CART site. 9th Annual ARM Meeting, San Antonio, Texas, March 22-26, 1999. [BNL-66170-AB]

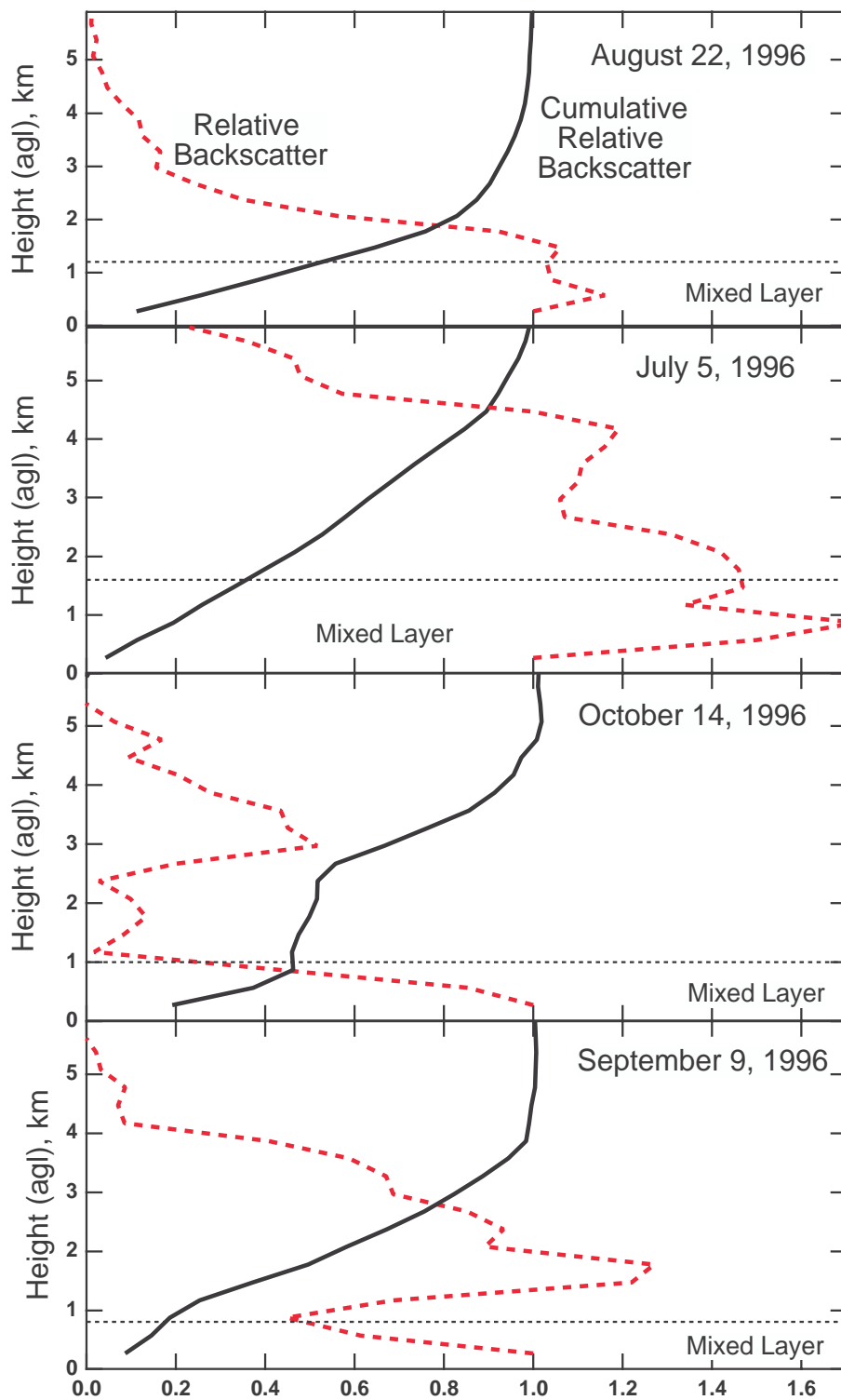
Schwartz, S. E., J. A. Ogren, and M. H. Bergin. Aerosol optical properties and direct shortwave radiative forcing: Dependence on size and composition. International Union of Geodesy and Geophysics--International Association of Meteorology and Atmospheric Sciences Symposium on Radiative Properties and Remote Sensing of Aerosols, IUGG 22nd General Assembly, Birmingham, England, 18 - 30 July, 1999. Invited Presentation.

9. Please update us on the status of submitted referred publications from the previous FY progress report.

See 7 above.

Observations-Bergin et al. JGR, 2000

Aerosol Lidar Backscatter on Cloud-Free Days at SGP



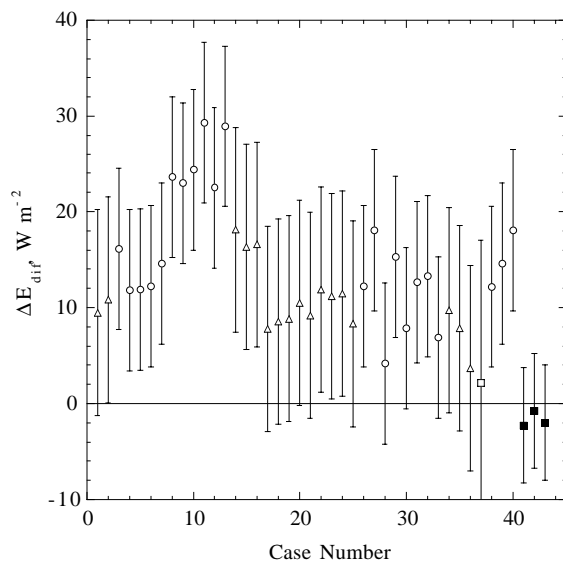
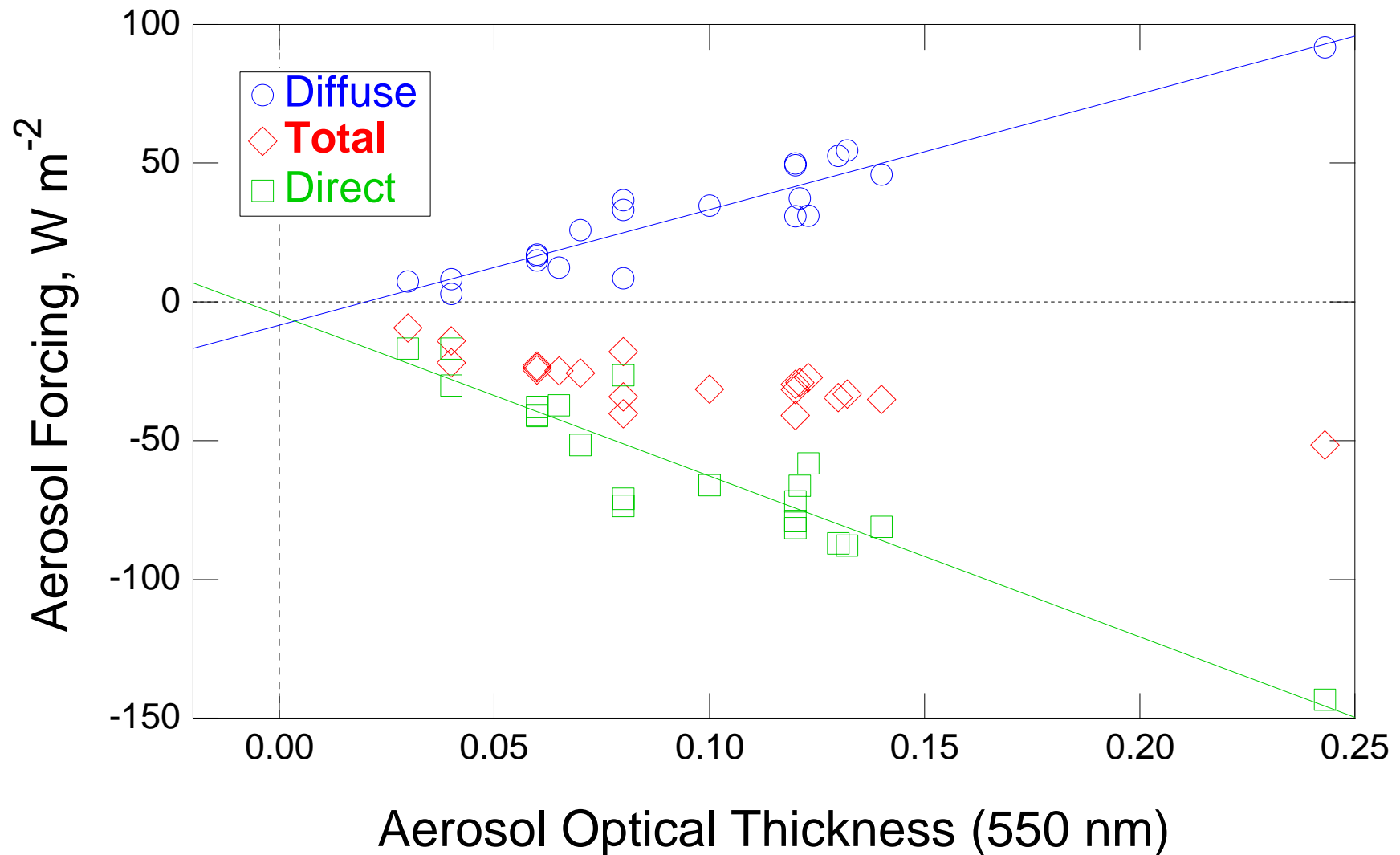


Figure 5. Difference between modeled (eight streams) and measured diffuse irradiance, $\Delta E_{\text{dif}} = E_{\text{dif}}^{\text{mod}} - E_{\text{dif}}^{\text{meas}}$ is shown for each case in Table 1, with uncertainties at the 75% confidence level (Table 2). Uncertainties are dependent on AOT: low AOT ($\tau_{550} \leq 0.1$, open circles), intermediate AOT ($0.1 < \tau_{550} \leq 0.2$, open triangles), and high AOT ($\tau_{550} > 0.2$, open square). High-altitude cases (solid squares) exhibit lower uncertainties because of very low AOT (< 0.01).

AEROSOL FORCING OF SURFACE IRRADIANCE

Dependence on Aerosol Optical Thickness

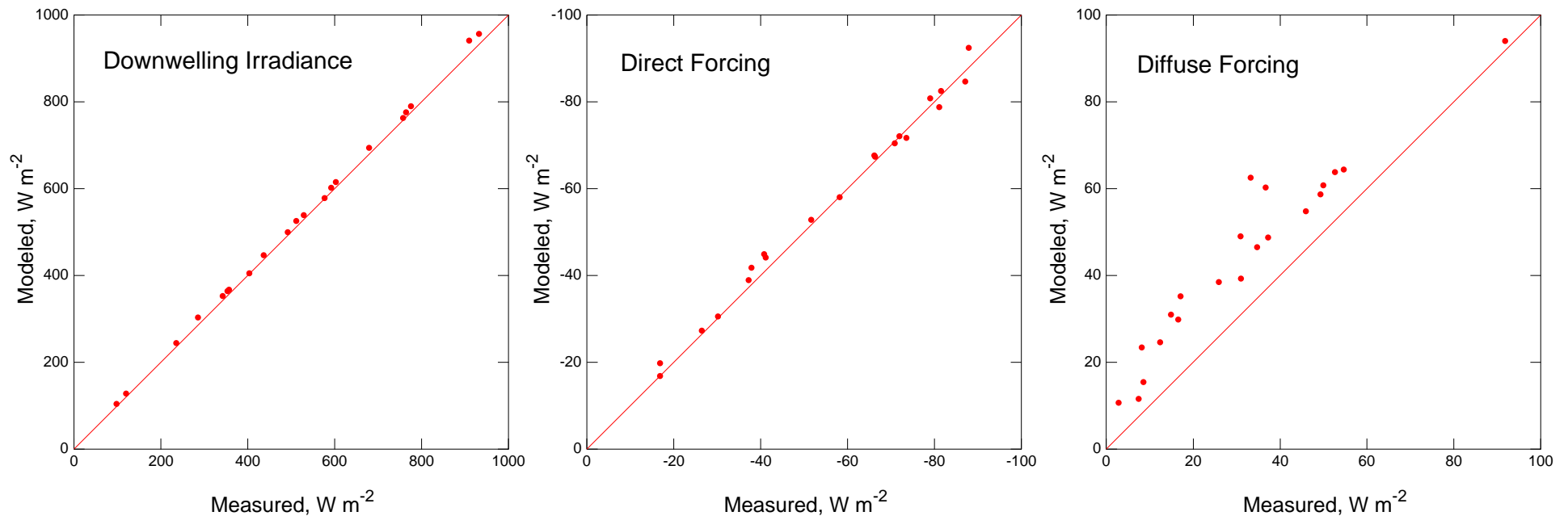
Cloud-free sky, DOE ARM Site, North Central Oklahoma



AEROSOL FORCING OF SURFACE IRRADIANCE

Comparison with Radiation Transfer Model

Cloud-free sky, DOE ARM Site, North Central Oklahoma



Note systematic discrepancy in diffuse forcing, as revealed also in Halthore *et al.* (*GRL*, 1998) and Halthore and Schwartz (*JGR*, in press, 2000).